

**Spectroscopic Study of Candidates for Kepler Asteroseismic Targets –
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e-mail: dlatham@cfa.harvard.edu*Received Month Day, Year***ABSTRACT**

We report spectroscopic observations of 23 candidates for Kepler asteroseismic targets and 10 other stars in the Kepler field, carried out at two observatories (see the footnote). For all these stars, we derive the radial velocities, effective temperature, surface gravity, metallicity, the projected rotational velocity, and estimate the MK type.

HIP 97513 and HIP 92132 are classified as suspected new single-lined spectroscopic binaries.

For 28 stars, the radial velocity is measured for the first time.

Key words: *Space missions: Kepler – Stars : radial velocities – Binaries: spectroscopic – Stars: atmospheric parameters*

1. Introduction

Kepler², a NASA space mission, shall be launched in April 2009 with the goal of detecting Earth-size and larger planets by means of the method of photometric transits (Borucki et al. 1997). Kepler photometry will also be used for detecting pulsations in program stars and deriving accurate values of their pulsation frequencies. This will allow an investigation of internal structure of these stars by means of asteroseismology (see, e.g., Christensen-Dalsgaard 2004).

In this paper, which is a sequel to the spectroscopic study of candidates for Kepler asteroseismic targets published by Molenda-Żakowicz et al. (2007, henceforth

¹The data used in this paper have been obtained at the *M.G. Fracastoro* station of the Catania Astrophysical Observatory and the F.L. Whipple Observatory, Mount Hopkins, Arizona.

²<http://kepler.nasa.gov/>

Paper I), we discuss 23 candidates for asteroseismic targets for Kepler and 10 other stars. Unfortunately, all 33 stars have Hipparcos parallaxes not precise enough to compute the luminosities, and therefore they were listed in Molenda-Żakowicz et al. (2006) as secondary candidates for Kepler asteroseismic targets, SATS. Since the stars have spectral types F, G or K, they are expected to show solar-like oscillations with amplitudes detectable in Kepler photometry.

Ten of these stars fall either just beyond the Kepler CCD chips or into star tracker corners, so that they are not expected to be observed in normal conditions. Therefore, in the present paper we have narrowed down the definition of the SATS to the 23 stars that fall onto active chips of the Kepler CCDs.

The paper is organised as follows. After giving an account of the spectroscopic observations and reductions in Sect. 2, in Sect. 3 we discuss stars showing variable radial velocity. In Sect. 4, we determine the effective temperature, surface gravity, metallicity, and MK spectral type of the stars. In Sect. 5, we give their projected rotational velocity. Sect. 6 contains a summary.

2. Observations and Reductions

The observations were carried out at the *M.G. Fracastoro* station (Serra La Nave, Mount Etna, elevation 1750 m) of the Catania Astrophysical Observatory (CAO), Italy (39 spectrograms) and at the F.L. Whipple Observatory (FLWO), Mount Hopkins, Arizona (6 spectrograms).

At CAO, we used a 91-cm telescope and the fiber-fed echelle spectrograph FRESCO. The spectra were recorded with the resolving power $R=21\,000$ in a spectral range that covered about $2\,500\text{ Å}$ in 19 orders. A thinned back-illuminated CCD SITe chip (SI033B) with $1024\times 1024\text{ }24\times 24\text{-}\mu\text{m}$ pixels was used as the detector. At FLWO, we used the 1.5-m Tillinghast reflector and the CfA Digital Speedometer with the resolving power $R=35\,000$. An intensified photon-counting Reticon was used as the detector. In this system, a single 45 Å spectrogram, centered at $\lambda \simeq 5187\text{ Å}$, was recorded in one exposure.

The IRAF³ software was used for the reduction and calibration of the spectrograms measured at CAO. For the spectrograms measured at FLWO, a special procedure described in detail in Latham et al. (1992) was employed. Detailed description of the reduction of the data and the extraction of the spectra has been given in Paper I.

The radial velocities of the stars observed at CAO were determined by the cross-correlation method provided by IRAF. For the templates, we used Arcturus or β Oph for which precise values of R.V. are available (Udry et al. 1999) and which were observed on the same nights as the program stars. For the spectro-

³IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

grams measured at FLWO, a grid of synthetic spectra based on model atmospheres of R.L. Kurucz and computed by Jon Morse was used as the templates (see Torres et al. 2002).

The majority of stars discussed in this paper had single spectrograms measured at CAO or FLWO. Nine stars were observed more than once; five were observed at both observatories. Therefore, before the analysis was started, the R.V. of these nine stars were moved to one reference system by subtracting 0.5 km s^{-1} from each FRESCO's measurement. This offset has been calculated using the mean values of R.V. measured for 15 G-type dwarfs with FRESCO and the CfA Digital Speedometers, as described in Paper I. All results discussed in the present paper are obtained from the merged data.

Table 1

Radial velocities (in km/s) of the program stars. The code in the last column indicates stars that fall onto the active chips of the Kepler CCDs, "A", stars that fall into CCD gaps, "G", or stars that fall into star tracker corners, "S". The individual velocities are not corrected for the shift between observatories

HIP	α_{2000}	δ_{2000}	HJD - 2400000	R.V.	s.e.	Instrument	code
91841	18 43 28.30	+47 42 13.0	4266.5839	-18.70	0.15	FRESCO	A
91841	18 43 28.30	+47 42 13.0	4312.4190	-18.02	0.20	FRESCO	A
91841	18 43 28.30	+47 42 13.0	4363.3105	-17.50	0.15	FRESCO	A
91841	18 43 28.30	+47 42 13.0	4368.6002	-18.20	0.36	Tillinghast	A
92053	18 45 44.79	+48 23 57.6	4266.3888	-35.84	0.28	FRESCO	G
92132	18 46 41.64	+44 41 06.5	4279.5254	-3.57	0.27	FRESCO	A
92132	18 46 41.64	+44 41 06.5	4363.3650	-1.34	0.25	FRESCO	A
92775	18 54 16.95	+42 59 00.4	4278.5515	-271.05	0.54	FRESCO	A
92941	18 56 09.26	+46 39 56.5	4289.5676	-17.46	0.13	FRESCO	G
92961	18 56 21.26	+45 30 53.1	4290.3441	-28.78	0.16	FRESCO	A
92961	18 56 21.26	+45 30 53.1	4313.5979	-28.54	0.33	FRESCO	A
93320	19 00 27.13	+45 41 32.1	4268.4200	-47.47	0.53	FRESCO	A
93320	19 00 27.13	+45 41 32.1	4280.7682	-46.97	0.39	Tillinghast	A
93320	19 00 27.13	+45 41 32.1	4286.8822	-47.02	0.37	Tillinghast	A
.....							
98793	20 03 55.17	+44 08 24.2	4266.5154	13.99	0.37	FRESCO	A

In Table 1, we give the individual radial velocity measurements not corrected for this offset. The table is available in electronic form from the Acta Astronomica

Archive (see the cover page). A sample, containing the heading, the first 14 rows and the last row, is printed above. In the first column we give the HIP number, in the second and the third column, the right ascension and declination, in the fourth, Heliocentric Julian Day of the middle of the exposure, in the fifth and sixth, the radial velocity, R.V., and the standard error, s.e., in the next column, the instrument used, and in the last column, the information whether the star falls onto the active pixels of Kepler CCDs, coded with “A”, into the gaps between CCD chips, coded with “G”, or into a star tracker corner, coded with “S”.

In Table 2, we list the nine stars for which we had two or more spectrograms. In the first column, we give the HIP number of the star, in the second, the number of spectrograms, in the third, the total time-span of observations in days, then, the mean radial velocity, R.V., in km s^{-1} , the ratio of external-to-internal error, e/i, the reduced χ^2 , and the probability that a star with constant velocity will have χ^2 value larger than the observed one, $P(\chi^2)$. For a detailed description of the method of computing the errors, we refer to Latham et al. (2002).

Table 2

Nine stars for which more than one spectrogram was measured: the number of spectrograms measured, the total time-span in days, the mean radial velocity, R.V., in km/s, the ratio of external-to-internal error, e/i, the reduced χ^2 , and the probability that a star with constant velocity will have χ^2 value larger than the observed one, $P(\chi^2)$

HIP	<i>N</i>	span	R.V.	s.e.	e/i	χ^2	$P(\chi^2)$
91841	4	102	−18.09	0.29	2.71	0.32	0.96
92132	2	84	−2.87	1.40	7.60	1.12	0.29
92961	2	23	−29.23	0.15	0.87	0.02	0.90
93320	3	19	−47.20	0.34	1.37	0.26	0.88
93469	2	17	−55.16	0.63	1.60	0.16	0.67
94022	2	16	−24.61	0.31	1.30	0.05	0.85
94918	2	0.1	−47.01	0.58	0.80	0.33	0.57
97513	2	59	−8.69	2.73	26.64	3.20	0.07
98793	2	14	13.71	0.32	1.43	0.05	0.81

3. Program Stars with Variable Radial Velocity

3.1. HIP 97513

HIP 97513 shows a very low value of $P(\chi^2)$. In the Hipparcos Catalogue (ESA 1997), it is listed as a binary with an ambiguous double-star solution. HIP 97513 was observed spectroscopically by Bartkevičius & Sperauskas (2005) who measured the star’s R.V. on two consecutive nights but found no variation. We have

used their values to compute an improved weighted mean radial velocity, $R.V. = -8.21 \pm 1.06$ km/s.

We classify HIP 97513 as a suspected single-lined spectroscopic binary.

3.2. HIP 92132

HIP 92132 is the second star from our sample which shows indications of variability in radial velocity. The R.V. measured by other observers range from -3.5 ± 0.8 km/s (Gontcharov 2006), through -4.1 km/s (Wielen et al. 2000) to -4.2 ± 19.9 (Bobylev et al. 2006).

Since Wielen et al. (2000) do not give the uncertainties of the R.V. and the uncertainty given by Bobylev et al. (2006) is very high, we did not include these data in calculating a mean radial velocity.

We classify HIP 92132 as a suspected single-lined spectroscopic binary.

4. Effective Temperature, Surface Gravity, Metallicity, and the MK Type

4.1. From a Comparison with Standard Stars

We determined T_{eff} , $\log g$ and $[\text{Fe}/\text{H}]$ of the program stars observed with the FRESCO instrument, using ROTFIT, which is an IDL code developed by A.F. and his coworkers (see, e.g., Frasca et al. 2003, 2006). The method, originally developed by Katz et al. (1998) and Soubiran et al. (1998), consists in comparing the spectra of program stars with a library of spectra of reference stars, and computing the weighted means of the astrophysical parameters of these five reference stars which best reproduce the target spectrum. The T_{eff} , $\log g$, and $[\text{Fe}/\text{H}]$ computed in this way are adopted as estimates of the astrophysical parameters of the program star. For the measure of the similarity of spectra, χ^2 is used. This method, as discussed by, e.g., Frasca et al. (2006), allows simultaneous and fast determination of T_{eff} , $\log g$, and $[\text{Fe}/\text{H}]$ even from spectrograms of low signal-to-noise ratio (S/N) or moderate resolution.

For the reference stars, we used 240 slowly rotating stars of which spectrograms are available from the ELODIE archive (Prugniel & Soubiran 2001). These stars have been listed in Table 7 of Paper I. Then, similarly as in Paper I, we performed parallel computations with ROTFIT using 109 reference stars observed with FRESCO. The FRESCO grid consists of the 82 stars listed in Table 8 of Paper I and 27 new reference stars which were observed in the same observing season as the program stars. In Table 5, which is available electronically from the Acta Astronomica Archive, we list all reference stars from the FRESCO library used in the present paper.

Adding the above-mentioned 27 new reference stars to the FRESCO grid did not change its limits in $\log T_{\text{eff}}$, $\log g$, and $[\text{Fe}/\text{H}]$, which are equal to [4750 K, 6750 K], [3.8, 4.6], and $[-0.5, 0.5]$, respectively, but made the grid more dense, and the estimated atmospheric parameters, more certain in comparison with the

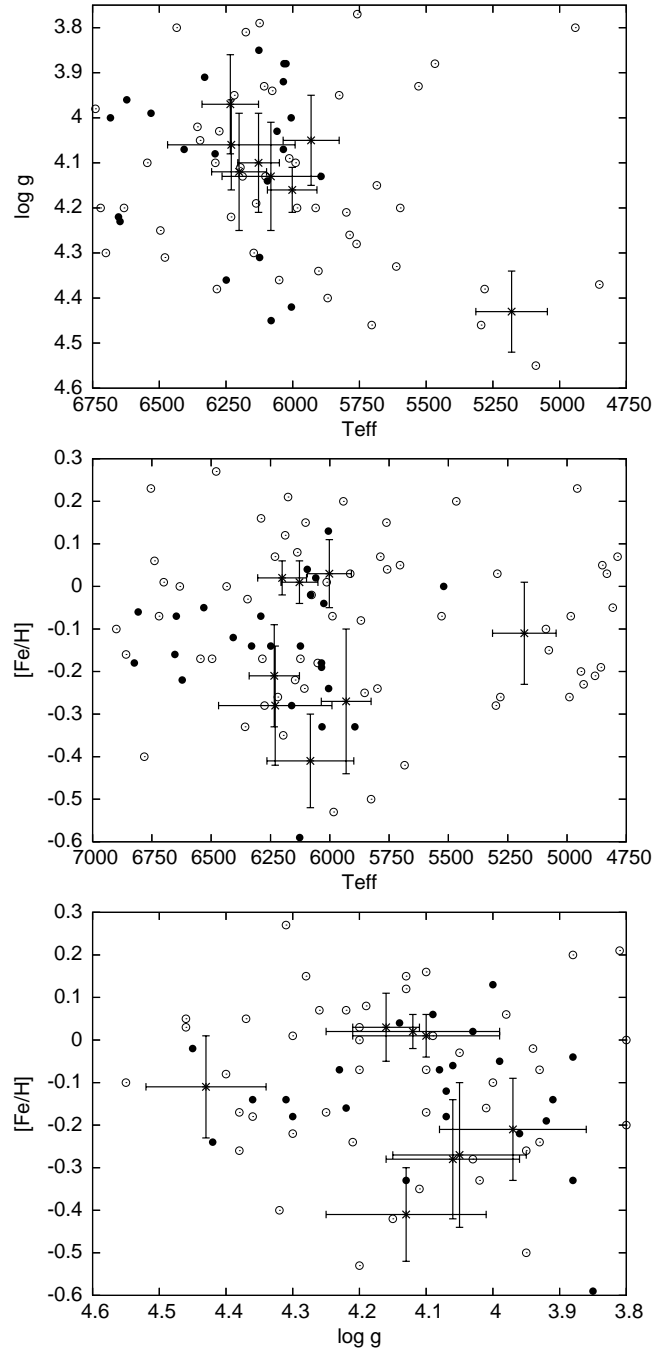


Fig. 1. Distribution of the FRESKO reference stars from Table 8 of Paper I (open circles), the new reference stars added in this paper (dots) and the program stars from Table 3 (asterisks) in the $T_{\text{eff}}-\log g$, $T_{\text{eff}}-[\text{Fe}/\text{H}]$ and $\log g-[\text{Fe}/\text{H}]$ planes. For program stars, 1σ error bars are shown. The diagrams show the regions occupied by the program stars.

results of Paper I. We show the new FRESCO grid in Fig. 1, where we plot the FRESCO reference stars from Table 8 of Paper I with open circles, the new reference stars, with dots, and the eight program stars which fall into the limits of the FRESCO grid, with asterisks.

In Tables 3 and 4, we list the T_{eff} , $\log g$, and $[\text{Fe}/\text{H}]$ of the 23 SATS and the 10 remaining program stars obtained by the method described above. We use a regular font for the atmospheric parameters obtained with the ELODIE grid and italics for the values obtained with the FRESCO grid. In the last but one column of the tables, we give the MK spectral type assigned using the spectral classification of the reference star which had its atmospheric parameters closest to the values computed for the program star. We find our classification consistent with the relations between T_{eff} and spectral type given by Johnson (1966) for dwarfs and giants. In the last columns, we list spectral types taken from the Simbad database.

In Fig. 2, we use open circles to plot the difference between the ELODIE and FRESCO based values of the effective temperature, $\Delta T_{\text{eff}} = T_{\text{eff}}(\text{ELODIE}) - T_{\text{eff}}(\text{FRESCO})$, the gravity, $\Delta \log g = \log g(\text{ELODIE}) - \log g(\text{FRESCO})$, and the metallicity, $\Delta[\text{Fe}/\text{H}] = [\text{Fe}/\text{H}](\text{ELODIE}) - [\text{Fe}/\text{H}](\text{FRESCO})$, for the eight stars for which the atmospheric parameters were determined from both grids. The weighted mean differences between the atmospheric parameters determined from these two grids are equal to -11 ± 30 K, 0.05 ± 0.03 dex, and 0.00 ± 0.03 dex for T_{eff} , $\log g$, and $[\text{Fe}/\text{H}]$, respectively. This shows that, as in Paper I, the results obtained from both grids agree well and can be safely used for our purpose.

4.2. From Model Atmospheres

For the five SATS observed at the FLWO, we derived global atmospheric parameters using model atmospheres. As in Paper I, for each program star we used one-dimensional correlations to identify the template in the library of synthetic spectra that gives the best match with the observed spectrum, and we chose the template that gave the highest peak correlation value averaged over all the observed spectra. We assumed solar metallicity for all stars. The parameters are printed with a bold face font in Table 3.

In Fig. 2, we use dots to plot the difference between T_{eff} , $\log g$ and $[\text{Fe}/\text{H}]$ obtained from the ELODIE grid and from model atmospheres. As can be seen from the figure, the ELODIE and model-atmosphere results agree satisfactorily to within their error bars. The highest discrepancy occurs in case of HIP 93469 for which the model-atmosphere value is 432 K higher than that obtained from the ELODIE grid.

5. Projected Rotational Velocity

In Table 5, we list projected rotational velocities of the program stars together with their standard deviations. The $v \sin i$ for the stars observed at CAO was determined with the Full Width at Half Maximum (FWHM) method for each order

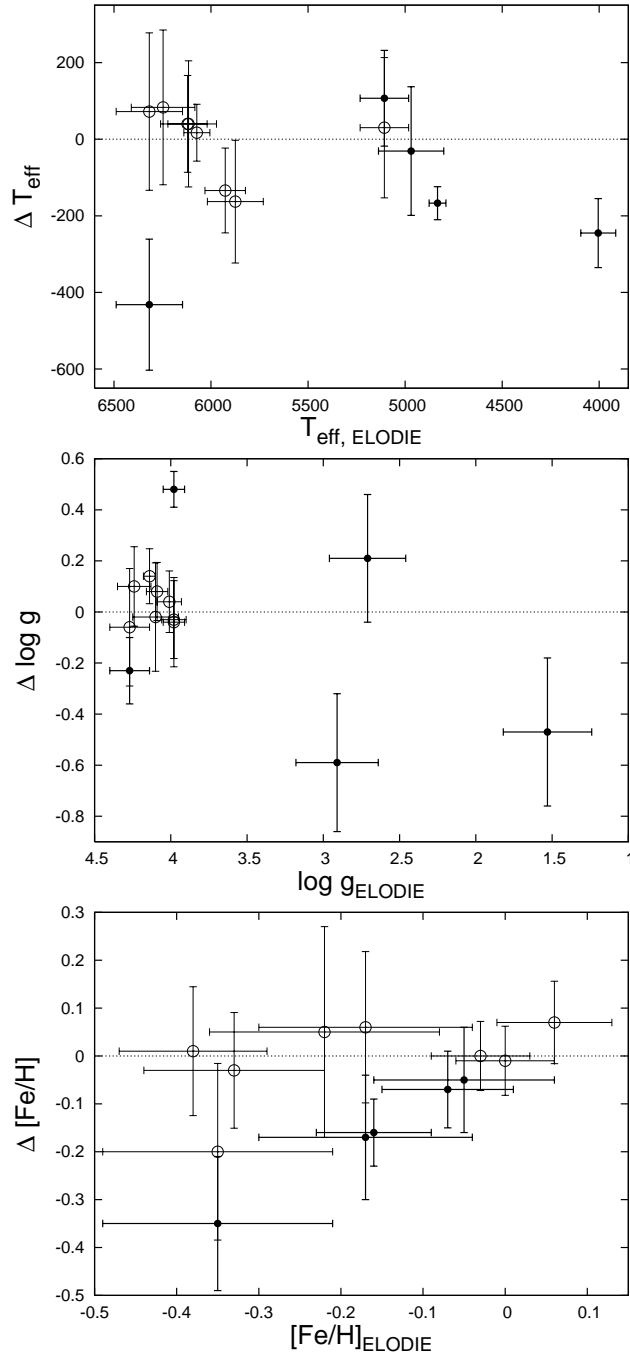


Fig. 2. The differences between T_{eff} (upper panel), $\log g$ (middle panel), and $[\text{Fe}/\text{H}]$ (lower panel) determined from the ELODIE and the FRESCO grid (open circles), or from the ELODIE and the model atmospheres (dots). The dotted lines indicate zero differences.

of the echelle spectrum which did not contain broad spectral lines. As templates,

Table 3

Astrophysical parameters and the MK types of 23 SATS determined with the use of the ELODIE library (regular font), FRESCO library (*italics*) or model atmospheres (**bold face**). For the model atmospheres, the solar metallicity was assumed. In the last column, we list spectral types from the literature

HIP	T_{eff}	s.d.	$\log g$	s.d.	[Fe/H]	s.d.	MK	Lit.
91841	4833	43	2.91	0.27	-0.07	0.08	G9III	K0
	5000		3.5		0.0			
92132	4947	155	2.50	0.16	-0.57	0.10	G3IV	G5
92775	5915	182	4.06	0.29	-1.68	0.19	sdF8	G2
92961	5927	104	4.24	0.11	0.00	0.06	G0V	F8
	<i>6061</i>	<i>38</i>	<i>4.14</i>	<i>0.11</i>	<i>0.01</i>	<i>0.04</i>		
93320	5107	125	4.27	0.13	-0.35	0.14	K1V	K3
	<i>5077</i>	<i>134</i>	<i>4.33</i>	<i>0.19</i>	<i>-0.15</i>	<i>0.12</i>		
	5000		4.5		0.0			
93469	6318	171	3.98	0.07	-0.17	0.13	F8IV	G0
	<i>6246</i>	<i>114</i>	<i>4.02</i>	<i>0.16</i>	<i>-0.23</i>	<i>0.09</i>		
	6750		3.5		0.0			
93607	6121	101	4.09	0.07	-0.03	0.06	F6IV	F5
	<i>6081</i>	<i>76</i>	<i>4.01</i>	<i>0.09</i>	<i>-0.03</i>	<i>0.04</i>		
93687	4865	78	2.66	0.09	-0.07	0.12	G9III	K0
93879	6116	144	3.98	0.08	-0.38	0.09	F8IV	F8
	<i>6076</i>	<i>80</i>	<i>4.01</i>	<i>0.13</i>	<i>-0.39</i>	<i>0.10</i>		
94022	4005	90	1.53	0.29	-0.16	0.07	K4III	K0
	4250		2.0		0.0			
94292	4895	152	2.68	0.32	-0.27	0.21	G8III	G8V
94409	4011	90	1.63	0.20	-0.13	0.05	K4III	M0
94918	5875	144	4.10	0.15	-0.22	0.14	G0V	G2V
	<i>6038</i>	<i>70</i>	<i>4.12</i>	<i>0.15</i>	<i>-0.27</i>	<i>0.17</i>		
94952	4072	66	1.75	0.10	-0.19	0.06	K4III	K5
94976	4976	156	2.55	0.09	-0.24	0.21	G5III	K0V
95237	4892	97	2.63	0.08	-0.11	0.12	G7III	G5
95654	6284	173	3.97	0.09	-0.08	0.08	F6IV	F5
96751	4601	44	2.30	0.16	-0.11	0.04	K1III	K2
96846	4599	48	2.27	0.12	-0.07	0.05	K1III	K2
97247	4040	72	1.74	0.07	-0.17	0.08	K4III	K5
97439	5370	118	1.49	0.34	0.06	0.07	G2Ib	G2
97513	4159	152	1.72	0.33	-0.20	0.06	K3III	K0
98793	4969	168	2.71	0.25	-0.05	0.11	G8III	–
	5000		2.5		0.0			

we used a grid of rotationally broadened spectra of a non-rotating star having T_{eff} , $\log g$, and [Fe/H] similar to that of the program star. The upper limit of 5 km s^{-1} was estimated according to the instrumental resolution of the spectrograms.

For the five SATS observed at the FLWO, we have used the Kurucz model

Table 4

Astrophysical parameters and MK spectral types of 10 remaining stars determined with the use of the ELODIE library (regular fonts) or FRESKO library (*italics*). In the last column, we list spectral types from the literature

HIP	T_{eff}	s.d.	$\log g$	s.d.	[Fe/H]	s.d.	MK	lit.
92053	4013	90	1.71	0.10	-0.16	0.07	K4III	M0
92941	4866	58	2.69	0.06	0.02	0.08	G9III	K0
93755	4673	149	2.72	0.15	-0.41	0.12	K0III	K0
94967	4912	176	2.64	0.32	-0.47	0.12	G8IV	G8V:
95859	6073	67	4.14	0.04	0.06	0.07	F8V	F8
	<i>6056</i>	<i>32</i>	<i>4.00</i>	<i>0.10</i>	<i>-0.01</i>	<i>0.05</i>		
95913	4859	56	2.79	0.15	-0.16	0.10	G9III	K0
96642	6247	164	4.01	0.08	-0.33	0.11	F5V	F5
	<i>6164</i>	<i>118</i>	<i>3.97</i>	<i>0.09</i>	<i>-0.30</i>	<i>0.05</i>		
96699	5019	142	2.80	0.22	-0.03	0.07	G8III	K0
97576	4593	46	2.27	0.14	-0.07	0.06	K1III	K2
97671	4357	171	2.03	0.23	-0.14	0.12	G9III	K0

spectra for the determination of $\nu \sin i$. In this method, we compared each observed spectrum with a library of synthetic spectra using correlation techniques described in Sec. 4.2. A typical standard deviation of these determinations is equal to 1 or 2 km s^{-1} . We list these values in Table 5, in the column headed “model”.

As can be seen from Table 5, the values of $\nu \sin i$ obtained from the two separate sets of data by means of the above-mentioned two methods agree well.

6. Summary

We present spectroscopic observations of 23 secondary candidates for Kepler asteroseismic targets (SATS) and of 10 other stars. The observations were carried out at the *M.G. Fracastoro* station of the Catania Astrophysical Observatory and the F.L. Whipple Observatory, Mount Hopkins, Arizona.

We find that all SATS but one, HIP92775, listed as a subdwarf by Ryan & Norris (1991), have solar-like metallicity or are slightly metal-deficient. They range in spectral type from early F to late K and therefore we expect all of them to show solar-like oscillations. 17 SATS are classified in this paper as subgiants or giants. These stars are particularly interesting from the asteroseismic point of view because the predicted amplitude of solar-like oscillations in the evolved stars is expected to be higher than in dwarfs (see, e.g., Kjeldsen & Bedding 1995).

Our sample contains also HIP97439 (= V1154 Cyg), G2Ib, which is a well-known Cepheid variable. The light curve of this star has been measured photoelectrically in Johnson UBV filters by Wachmann (1976), Szabados (1977) and Henden

Table 5

Projected rotational velocities determined from a grid of Kurucz model spectra and by means of the FWHM method

HIP	$v \sin i$ [km s ⁻¹] (model)	$v \sin i$ [km s ⁻¹] (FWHM)	s.d. [km s ⁻¹] (FWHM)	HIP	$v \sin i$ [km s ⁻¹] (FWHM)	s.d. [km s ⁻¹] (FWHM)
SATS				The remaining stars		
91841	0.5	<5		92053	<5	
92132		<5		92941	<5	
92775		7.0	1.8	93755	<5	
92961		<5		94967	5.2	1.6
93320	1.5	<5		95859	<5	
93469	11.0	8.5	2.0	95913	<5	
93607		<5		96642	20.5	2.0
93687		<5		96699	<5	
93879		15.7	1.2	97576	<5	
94022	0.0	<5		97671	<5	
94292		<5				
94409		<5				
94918		<5				
94952		<5				
94976		<5				
95237		17.7	0.7			
95654		12.2	1.1			
96751		<5				
96846		<5				
97247		5.3	1.7			
97439		12.3	1.6			
97513		<5				
98793	9.0	<5				

(1979), in UBVR filters by Berdnikov (1987) and Berdnikov (1993), and in uvby β filters by Arellano et al. (1998). The typical precision of these observations was ± 0.01 mag. The only CCD observations of V1154 Cyg were made in blue light by Turner et al. (1999) and have the precision of around ± 0.3 mag.

V1154 Cyg was included in the search for double mode Cepheids carried out by Szabados (1977) and Henden (1979), but was not classified as such. We note, however, that the relatively short period of pulsations of V1154 Cyg, equal to 4.925537 days (Samus et al. 2004), makes this star similar to the 11 double mode Cepheids listed by Balona (1985) and to the four Cepheids which were supposed by Kovtyukh et al. (2003) to show non-radial pulsations in line profiles. We expect that the high-precision Kepler photometry will allow checking whether V1154 Cyg indeed does not show any of the above mentioned phenomena, or they are present but with

an amplitude too small to allow their detection in the photometric data available to date.

From all spectrograms, we derive the radial velocities. The results are given in Table 1, available in electronic form from the Acta Astronomica Archive (see the cover page). In addition, the spectrograms obtained at the *M.G. Fracastoro* station of the Catania Astrophysical Observatory are used to determine the effective temperature, surface gravity, metallicity, and MK type by means of the ROTFIT code (Frasca et al. 2003, 2006). The spectrograms obtained at the F.L. Whipple Observatory are used to determine the effective temperature and surface gravity by means of a two-dimensional correlation technique TODCOR (Zucker & Mazeh 1994 and Torres et al. 2002). The results obtained from these two different methods applied to two different data sets, given in Table 3, agree well in all but one case. We also estimate the projected rotational velocity from two separate sets of data using two independent methods (see Table 5) obtaining good agreement.

Acknowledgements. This work was supported by MNiSW grant N203 014 31/2650, the University of Wrocław grants 2646/W/IA/06 and 2793/W/IA/07, the Italian government fellowship BWM-III-87-Włochy/ED-W/06 and the Socrates-Erasmus Program “Akcja 2” 2006-2007, contract No. 33.

J.M.-Ż. acknowledges the European Helio- and Asteroseismology Network HELAS for the financial support and thanks Marcin Giełda for help in observations.

We acknowledge the partial support from the Kepler mission under cooperation agreement NCC2-1390 (D.W.L., PI).

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